Appendix B
Design Examples

Design examples for conduits, culverts, and pipes are presented in this appendix. Each equation in this manual is used in the order presented in its chapter. Once a variable is defined, that value is used throughout the remaining calculations. The design method for corrugated metal pipe from ASTM A 796 is included for Chapter 4. This method also applies to corrugated aluminum pipe using the ASTM B 790 method of design.

At the end of this appendix is a demonstration of a finite element method computer code used to analyze concrete rectangular and oblong shapes.

Chapter 2: Cast-in-Place Conduits for Dams

Prism Loads

Unit Weight of Soil, Water, and Saturated Soil

γ_s = 21,210 N/m^3 (135 pcf) - Saturated soil

γ_d = 18,850 N/m^3 (120 pcf) - Dry soil

γ_w = 9,800 N/m^3 (62.5 pcf) - Water

Height of Soil, Water and Saturated Soil above the Crown of the Conduit.

H_d = 2.44 m (8 ft) - Dry soil column

H_w = 15.24 m (50 ft) - Water column

H_s = 6.10 m (20 ft) - Saturated column

Vertical Pressures

Vertical pressures for the given soil condition; dry soil, dry and saturated soil, or reservoir condition (saturated soil under water).

$W_{w1} = \gamma_d \cdot H_d$	N/m^2 (psf)	(2-1) Dry
or		
$W_{w2} = \gamma_d \cdot H_d + \gamma_s \cdot H_s$	N/m^2 (psf)	(2-1) Dry and saturated
or		
$W_{w3} = \gamma_w \cdot H_w + (\gamma_s - \gamma_w) \cdot H_s$	N/m^2 (psf)	(2-1) Reservoir

W_{w1} = 45,994 N/m^2 (960 psf)

W_{w2} = 1,753,754 N/m^2 (3,660 psf)

W_{w3} = 218,953 N/m^2 (4,572 psf)

Internal Water Pressure

H_G = 36.6 m (120 ft) - Hydraulic gradient

r + 1.22 m (4 ft) - Internal radius of conduit (+ or -) depending on the position of interest - top or bottom of the conduit

$w_i = \gamma_w \cdot (H_g + r)$ N/m^2 (psf)

w_i = 370,636 N/m^2 (7,738 psf)

Concentrated Live Loads

Vertical Pressure

P = 44,480 N (10,000 lb)

y = 0.305 m (1 ft) - Y - Cartesian coordinate

z = 0.610 m (2 ft) - Z - Cartesian coordinate

x = 0.915 m (3 ft) - X- Cartesian coordinate

$$R = \sqrt{x^2 + z^2 + y^2} \text{ m (ft) – Radial distance from point load}$$

R = 1.141 m (3.742 ft)

$$W_c = \frac{3 \cdot P \cdot z^3}{2 \cdot \pi \cdot R^5} \text{ N/m}^2 \text{ (psf) – Vertical pressure from a concentrated load} \qquad (2\text{-}3)$$

w_c = 2,490 N/m^2 (52 psf)

Horizontal Pressure

r = 0.610 m (2 ft) - Surface radius from point load

μ = 0.3 Poisson's ratio: 0.5 for saturated cohesive soils, 0.2 to 0.3 for other soils

$$p_c = \frac{P}{2 \cdot \pi} \cdot \left[\frac{3 \cdot r^2 \cdot z}{R^5} - \frac{(1 - 2 \cdot \mu)}{(R + z) \cdot R} \right] \text{Nsm (psf)} \qquad (2\text{-}4)$$

p_c = 1,074 N/m^2 (23 psf)

Trench Backfill Loads

Trench with No Superimposed Fill, Condition I

Vertical Trench Load Values for $K_{\mu'}$ and g are

$K_{\mu'}$ = 0.15	Granular w/o cohesion $K_{\mu'}$ = 0.1924, g = 15,700 N/m^3 (100 pcf)		
H = 2.44 m (8 ft)	Sand and gravel	18,850 (120)	0.165
	Saturated topsoil	17,280 (110)	150
	Ordinary clay	15,710 (100)	0.130
B_d = 1.52 m (5 ft)	Saturated clay	20,420 (130)	0.110
	Maximum design load	22,000 (140)	0.110

$$C_d = \frac{1 - \exp\left[-2 \cdot K_{\mu'} \cdot \left(\frac{H}{B_d}\right)\right]}{2 \cdot K\mu'} \text{ Trench coefficient} \tag{2-7}$$

c_d = 1.274 Dimensionless

B_c = 1.22 m (4 ft)

$$W_{e1} = C_d \cdot \gamma_d \cdot B_d^2 \text{ N/m (lbf/ft)} \tag{2-5}$$

or

$$W_{e2} = \gamma_d \cdot B_c \cdot H \text{ N/m (lbf/ft)} \tag{2-6}$$

W_{e1} = 55,483 N/m (3,812 lbf/ft)

W_{e2} = 56,113 N/m (3,840 lbf/ft)

Horizontal Trench Pressure

$\phi = 30\,°$ = Internal friction angle in degrees

H = 6.1 m (20 ft)

γ_d = 18,850 N/m^3 (120 pcf) for dry soil

$$P_{e2} = \gamma_d \cdot H \cdot \left[\tan^2\left(45\,° - \frac{\phi}{2}\right)\right]^2 \text{ N/m}^2 \text{ (psf)} \tag{2-8}$$

p_{e2} = 38,828 N/m^2 (800 psf)

Trench with Superimposed Fill, Condition II

Vertical Trench Load

H_f = 3 m (10 ft) - Height of superimposed fill above the top of the trench

H_h = 1.5 m (5 ft) - Height of effective fill in trench

H_p = 1.2 m (4 ft) - Height of projected conduit above the natural ground

$$W_{w3} = C_d \cdot \gamma_d \cdot B_d^2 + \left(\frac{H_f}{H_c + H_p}\right) \cdot \left(1.5 \cdot \gamma_d \cdot B_c \cdot H_h - C_d \cdot \gamma_d \cdot B_d^2\right) \text{ N/m (lbf/ft)} \tag{2-9}$$

or

$$W_{e4} = \gamma_d \cdot B_c \cdot H_h + \left(\frac{H_f}{H_c + H_p}\right) \cdot \left(1.5 \cdot \gamma_d \cdot B_c \cdot H_h - \gamma_d \cdot B_c \cdot H_h\right) \text{ N/m (lbf/ft)} \tag{2-10}$$

W_{e3} = 53,946 N/m (3,724 lbf/ft)

W_{e4} = 41,584 N/m (2,900 lbf/ft)

Horizontal Trench Pressure

$$P_{e3} = \gamma \cdot H_h \cdot \left[\tan^2\left(45 \cdot \deg - \frac{\phi}{2}\right)\right] + \left(\frac{H_f}{H_c + H_p}\right) \cdot \left\{0.5 \cdot \gamma \cdot H_h - \gamma \cdot H_h \cdot \left[\tan^2\left(45 \cdot \deg - \frac{\phi}{2}\right)\right]\right\} \quad (2\text{-}11)$$

P_{e3} = 11,362 N/m (242 lbf/ft)

Embankment Condition III

Vertical Loads in N/m (lbf/ft) using γ_d = 18,850 N/m^3 (120 pcf) dry soil:

Case 1: $W_{e5} = 1.5 \cdot \gamma_d \cdot B_c \cdot H_c$ (2-12)

Case 2: $W_{e6} = \gamma_d \cdot B_c \cdot H_c$ (2-13)

Vertical Loads in N/m^2 (psf)

Case 1: $W_{e7} = 1.5 \cdot \gamma_d \cdot H_c$ (2-14)

Case 2: $W_{e8} = \gamma_d \cdot H_c$ (2-15)

W_{e5} = 210,423 N/m (14,400 lbf/ft)

W_{e6} = 140,282 N/m (9,600 lbf/ft)

W_{e7} = 172,478 N/m^2 (3,600 psf)

W_{e8} = 114,985 N/m^2 (2,400 psf)

Horizontal Loads in N/m^2 (psf)

Case 1: $p_{e4} = 0.5 \cdot \gamma_d \cdot H_c$ N/m^2 (psf) (2-16)

Case 2: $p_{e5} = \gamma_d \cdot H_c$ N/m^2 (1,200 psf) (2-17)

p_{e4} = 57,493 N/m^2 (1,200 psf)

p_{e5} = 114,985 N/m^2 (2,400 psf)

Notes on Loading Conditions for Embankments

Case 1: $p_e/w_e = 0.3$ and $k_a = 0.50$

Case 2: $p_e/w_e = 1.00$ and $k_a = 1.00$

Chapter 3: Circular Precast Concrete Pipe for Small Dams and Major Levees

D-Load Analysis

Load Factor for Trench Condition

Bedding Type	Load Factor
Ordinary	1.5
First Class	1.9
Concrete Cradle	2.5

Load Factors for Embankment Condition

Projection Ratio ρ	Concrete Cradle X_a	Other Projection Bedding X_a
0.0	0.150	0.000
0.3	0.743	0.217
0.5	0.856	0.423
0.7	0.811	0.594
0.9	0.678	0.655
1.0	0.638	0.638

Type of Bedding X_p	
Impermissible	1.310
Ordinary	0.840
First Class	0.707
Concrete Cradle	0.505

$X_a = 0.811$

$X_p = 0.505$

$$B_f = \frac{1.431}{X_p - \left(\frac{X_a}{3}\right)} \tag{3-1}$$

ASTM C76 Class and $D_{0.01}$

	Class	$D_{0.01}$
$B_f = 6.098$		
$W_1 = 145{,}940$ N/m (10,000 plf)	I	40 (800)
$W_e = 175{,}130$ N/m (12,000 plf)	II	50 (1,000)
* $H_f = 1.3$ Factor of Safety	III	65 (1,350)
	IV	100 (2,000)
$S_i = 1{,}200$ mm (4 ft)	V	140 (3,000) *

$$D_{\eta\zeta\eta\Theta} = \frac{W_{\omega}}{B_{\acute{\omega}}} \cdot \frac{H_{\acute{\omega}}}{S_{\varkappa}} = \frac{W_{\omega}\,(H_{\omega})}{B_{\acute{\omega}}(S_{\varkappa})} \quad (3\text{-}2)$$

* $D_{0.01}$ = 57 N/m/mm (1,172 plf/ft) ASTM C76M Class III

Chapter 4: Corrugated Metal Pipe for Rural Levees

Design in accordance with ASTM A 796 or ASTM B 790

Earth Load (EL)

H = 3 m (10 ft)

w = 18,850 N/m^2 (120 pcf)

$EL = H \cdot w$ N/m^2 (psf)

EL = 56,550 N/m^2 (1,220 psf)

Live Load (LL)

Live Loads Under Highways and Railroads

Height of Cover, m (ft)	Highway, N/m^2 (psf)	Railroad, N/m^2 (psf)
0.3 (1)	86,180 (1,800)	
0.6 (2)	38,300 (800)	181,940 (3,800)
0.9 (3)	28,730 (600)	
1.2 (4)	19,150 (400)	
1.5 (5)	11,970 (250)	114,910 (2,400)
1.8 (6)	9,580 (200)	
2.1 (7)	8,380 (175)	
2.4 (8)	4,790 (100)	76,610 (1,600)
3.0 (10)		52,670 (1,100)
3.7 (12)		38,300 (800)
4.6 (15)		28,730 (600)
6.1 (20)		14,360 (300)
9.1 (30)		4,790 (100)

LL = 38,200 N/m^2 (800 psf) - Live load includes impact

$P = EL + LL$ N/m^2 (psf)

P = 94,850 N/m^2 (2,000) psf) - Total load on conduit

Required Wall Area

S = 1.2 m (4 ft) - Span of conduit

$T = \frac{(P \cdot S)}{2}$ Thrust per length of conduit

T = 56,910 N/m (4,000 lbf/ft) - Thrust per length of conduit

SF = 2 Factor of Safety

f_y = 227,530,000 N/m^2 (33,000 psi) - Steel yield strength

$A = \frac{T \cdot SF}{f_y} \cdot 1000$ mm^2/mm (in.^{2}/ft) Required area of wall

A = 0.5002 mm^2/mm (0.2424 in.^{2}/ft) - Required area of wall

Critical Buckling Stress

k = 0.22 Soil stiffness factor for granular side fill material

$E = 2 \cdot 10^{11}$ N/m^2 (29,000,000 psi) Modulus of elasticity of steel

$f_u = 3.10 \cdot 10^8$ N/m^2 (45,000 psi) Ultimate strength of metal

r = 4.3713 mm (0.1721 in.) Radius of gyration (from ASTM)

s = 1,220 mm (48 in.) Conduit span

$$f_{c1} = f_u - \frac{f_u^2}{48 \cdot E} \cdot \left(\frac{k \cdot s}{r}\right)^2$$ Buckling strength of conduit wall

or

$$f_{c2} = \frac{12 \cdot E}{\left(\frac{K \cdot s}{r}\right)^2}$$

$$f_c = if\left(s < \frac{r}{k} \cdot \sqrt{\frac{24 \cdot E}{f_u}}, f_{c1}, f_{c2}\right)$$

$f_c = 2.72 \cdot 10^8$ N/m^2 (39,523 psi) - This value is greater than the yield strength of the material; therefore, the wall area calculated is adequate. If this value were less than the yield strength then the wall area would need to be recalculated with the lesser value.

Required Seam Strength

SF_s = 3 Safety factor for seams

$SS = T \cdot SF_s$ Required seam strength in N/m (lbf/ft)

SS = 170,730 N/m^2 (12,000 lbf/ft) - Check values with tables in ASTM A 796 or ASTM B 790

Handling and Installation Strength

I - 39,198 mm^4/mm (2.392 in.^{4}/ft) - Moment in Inertia of the section selected from the ASTM

$$FF = \frac{S^2}{E \cdot I} \cdot 1{,}000{,}000 \text{ mm/N } (FF/10^6 \text{ in./lb})$$

FF = 0.00019 mm/N (0.00003 in./lbf) - Flexibility factor shall not exceed the value in the ASTM

Flexibility Factors

	Trench	Embankment
Depth of Corrugation, mm (in.)	FF, mm/N (in./lb)	FF, mm/N (in.lb)
6 (1/4)	0.255 (0.043)	0.255 (0.043)
13 (1/2)	0.343 (0.060)	0.255 (0.043)
25 (1)	0.343 (0.060)	0.188 (0.033)
50 (2 (round pipe))	0.114 (0.020)	0.114 (0.020)
50 (2 (arch))		0.171 (0.030)
140 (5-1/2 (round))	0.114 (0.020)	0.114 (0.020)
140 (5-1/2 (arch))		0.171 (0.030)

Minimum Cover Design

d = 13 mm (1/2 in.) - Depth of corrugations

A_L = 142,340 N (32,000 lb) - Maximum highway axle load

Highway Loadings

Class	Maximum Axle Load, N (lb)
H 20	142,340 (32,000)
HS 20	142,340 (32,000)
H 15	106,760 (24,000)
HS 15	106,760 (24,000)

$$H_{min} = \text{if}\left[0.23 < \sqrt{\frac{A_L \cdot d}{E \cdot I}}, \frac{S}{8}, \text{if}\left(0.45 > \sqrt{\frac{A_L \cdot d}{E \cdot I}}, \frac{S}{4}, 0.55 \cdot S \cdot \sqrt{\frac{A_L \cdot d}{E \cdot I}}\right)\right]$$

H_{min} = 0.3 m (1 ft) - minimum cover for highway loads and is never less than 0.3 m (1 ft)

Check the requirements for railroad and aircraft loads.

Pipe-Arch Bearing Design

Maximum height of fill over arch pipe assuming 191,520 N/m^2 (2 tsf) bearing capacity for the soil

r_c = 0.46 m (1.5 ft) - corner radius of pipe-arch

$$H_{max} = \frac{66.7 \cdot r_c}{S} \cdot 0.3048 \text{ m } (H_{max}/0.3048 = \text{ft}) \text{ Maximum cover}$$

H_{max} = 7.79 m (25 ft)

Chapter 5: Culverts

Use the same design procedure as developed in Chapter 3 for precast pipe. Use the bedding load factors as defined in American Concrete Pipe Association Concrete Pipe Design Manual (1992).

Circular Concrete Culvert, Class B Bedding, Embankment Condition

$$B_f = \frac{C_A}{C_N - xq} \tag{5-1}$$

$C_A = 1.431$

$C_N = 0.707$

$x = 0.594$

$A = 0.33$

$P = 0.7$

$C_c = 3$

$H = 8$

$B_c = 4$ ft

$E = 0.50$

$$q = \frac{AP}{C_c}\left(\frac{H}{B_c} + EP\right) \leq 0.33$$

$$q = \frac{0.33(0.7)}{3}\,(2 + 0.5(0.7)) = 0.181 \geq 0.33 \tag{5-2}$$

Bedding factor B_f

$$B_f = \frac{1.431}{[0.707 - 0.594\ (0.181)]} = 2.387$$

$D_{0.01}$ Calculation

$$D_{0.01} = \frac{W_T\ H_f}{S_i\ B_f}$$

$S_i = B_c = 4$ ft

$H_f = 1.0$

$B_f = 2.387$

$W_T = 1.5\ \gamma\ B_c\ H_h$: $\gamma = 120$ pcf

$$H_h = 8 + \frac{4}{2} = 10 \text{ ft}$$

$W_T = 1.5(120)(4)(10) = 7200$ lbf/ft

$$D_{0.01} = \frac{7200\ (1)}{4\ (2.387)} = 754\ \frac{lb}{ft/ft}$$

Use Class I, C76 Pipe

Chapter 6: Plastic Pipe for Other Applications

Pipe Stiffness

D = 0.250 m (10 in.) - Pipe diameter

$R = \frac{D}{2}$ R = 0.125 m (5 in.) - Pipe radius

t = 8 mm (0.134 5 in.) - Wall thickness

$E_p = 3.03 \cdot 10^9$ N/m^2 (440,000 psi) - Initial modulus of elasticity (plastic)

$I = \frac{t^3}{12} \cdot 10^{-9}$ m^4/m (in.^{4}/in.) Moment of inertia

$I = 4.27 \cdot 10^{-8}$ m^4/m (0.0026 in.^{4}in.)

$$FF = \frac{D^2}{E \cdot I} * 1000 < = 0.542 \text{ m/N (95 in./lb)} \qquad (6\text{-}1)$$

FF = 0.4834 m/N (85 in.lb)

$$PS = \frac{E \cdot I}{0.149 \cdot R^3} > = 98{,}946/D \text{ N/m/m } (565/D \text{ lb/in./in.}) \qquad (6\text{-}2)$$

$$PS = 444{,}237 \geq \frac{98{,}946}{D} = 395{,}784 \; OK$$

Deflection

D_L = 2.5 Deflection lag factor for long-term prediction

K = 0.11 Bedding constant

$E' = 6.89 \cdot 10^6$ N/m^2 (1,000 psi) - Soil modulus

P = 69,000 N/m^2 (10 psi) - Service pressure at the crown of the pipe

$$\frac{\Delta Y}{D} = \frac{D_L \cdot K \cdot P}{0.149 \cdot (PS) + 0.061 \cdot (E')} \cdot 100 \text{ percent} \qquad (6\text{-}3)$$

$\frac{\Delta Y}{D}$ = 3.90% - Pipe deflection

Wall Stress (Crushing)

P_{ST} = 68,950 N/m^2 (1,440 psf) - Short-term pressure at the crown of the conduit

P_{LT} = 68,950 N/m^2 (1,440 psf) - Long-term pressure at the crown of the conduit

f_i = 3.03 · 10^9 N/m^2 (440,000 psi) Initial tensile strength of the pipe material

f_{50} = 1.09 · 10^9 N/m^2 (158,400 psi) - 50-year tensile strength of the pipe material

D = 0.3 m (1 ft) - Diameter of pipe

$$T_{ST} = D \cdot \frac{P_{ST}}{2} T_{ST} = 10{,}343 \text{ N/m (720 lbf/ft)} - \text{Short-term wall thrust} \tag{6-4}$$

$$T_{LT} = D \cdot \frac{P_{LT}}{2} T_{LT} = 10{,}343 \text{ N/m (720 lbf/ft)} - \text{Long-term wall thrust} \tag{6-5}$$

$$A \geq 2 \cdot \left(\frac{T_{ST}}{f_i} + \frac{T_{LT}}{f_{50}} \right) \cdot 10^6 \; A = 25.8 \text{ mm}^2\text{/m (0.0124 in.}^2\text{/ft)} - \text{Wall area} \tag{6-6}$$

Ring Buckling

H = 3 m (10 ft) - Height of soil above the crown of the pipe

H_w = 6 m (20 ft) - Height of water above the crown of the pipe

R = 0.3 m (12 in.) - Mean radius

$$B = 1 - 0.33 \cdot \frac{h_w}{h} \text{ Buoyancy factor } B = 0.34$$

E = 9.65 · 10^8 N/m^2 (140,000 psi) - 50-year Modulus of elasticity

M_s = 11.72 · 10^6 N/m^2 (1,700 psi) - Soil modulus

A = 3,050 mm^2/m (1.44 in.^{2}/ft) - Wall area

I = 42,610 mm^4/m (0.0026 in.^{4}/in.) - Moment of inertia of the wall section

$$f_{cr} = \frac{0.77 \cdot R}{A} \cdot \sqrt{\frac{B \cdot M_s \cdot E \cdot I}{0.149 \cdot R^3}} \text{ N/m}^2 \; (fa* \; 12 \text{ (psi)}) - \text{Wall buckling stress} \tag{6-7}$$

$$f_{cr} = \frac{f_a}{2} FS = 2\, f_{cr} = 7.6424 \cdot 10^6 \ \text{N/m}^2 \ (1{,}096 \text{ psi})$$

Hydrostatic Buckling

$\nu = 0.39$ Poisson's ration

$K = 1.5\ (10)^{-12}$ SI, 216 non-SI

$$P_{cr} = C\left(\frac{KEI}{(1 - \nu^2)R^3}\right) \cdot 0.7 \ \text{N/m}^2 \ \text{(psf)} \ - \ \text{Buckling stress} \qquad (6\text{-}8)$$

C = Ovality = 0.7 for 4 percent deflection

P_{cr} = 1,886 N/m^2 (37.3 psf) - Field stress or radial pressure from the water

Wall Strain Cracking

t_{max} = 6 mm (0.25 in.) - Thickness of pipe wall

D = 250 mm (10 in.) - Pipe diameter

$\frac{\Delta Y}{D} = 3.9\%$ Ratio of pipe deflection to pipe diameter

$$\varepsilon_b = \frac{t_{\max}}{D} \cdot \left[\frac{0.03 \cdot \frac{\Delta Y}{D}}{1 - \left(0.02 \cdot \frac{\Delta Y}{D}\right)}\right] \text{mm/mm (in./in.)} \ - \ \text{Wall strain} < \text{strain limit/2} \qquad (6\text{-}9)$$

$\varepsilon_b = 0.003 < 0.05/2 = 0.025$ OK

Chapter 7: Ductile Iron Pipe and Steel Pipe for Other Applications

Earth Load Limited by:

Bending Stress

$f = 3.31 \cdot 10^8$ N/m^2 48,000 psi) - Design stress

t = 6 mm (0.25 in.) - Wall thickness

D = 250 mm (10 in.) - Pipe diameter

$E = 165.5 \cdot 10^9$ N/m^2 (24,000,000 psi) - Modulus of elasticity

$E' = 3.45 \cdot 10^6$ N/m^2 (500 psi) - Soil modulus DIPRA Type 4 bedding

K_b = 0.157 Bending moment coefficient

K_x = 0.096 Deflection coefficient

$\Delta x/D$ = 0.03 Deflection limit

$$P_v = \frac{f}{3\left(\frac{D^2}{t^2} - \frac{D}{t}\right)\left\{K_b - \frac{K_x}{\left[\frac{8\frac{E}{E'}}{\left(\frac{D}{t} - 1\right)^3} + 0.732\right]}\right\}} \tag{7-1}$$

P_{v1} = 458,267 N/m^2 (10,279) psf)

Deflection

$$P_v = \left(\frac{\Delta X/D}{12K_x}\right)\left(\frac{8E}{\left(\frac{D}{t_m} - 1\right)^3} + 0.732\ E'\right) \tag{7-2}$$

P_{v2} = 578,439 N/m^2 (12,061 psf)

Chapter 8: Pipe Jacking

B_t = 1.2 m (4 ft) - Diameter of pipe

w = 18,850 N/m^3 (120 pcf) - Unit weight of soil

K_μ = 0.130 Soil constant

H = 15 m (50 ft) - Height of soil

c = 4,790 N/m^2 (100 psf) - Cohesion

$$C_t = 1 - \frac{\exp\left[-2 \cdot K_{\mu'} \cdot \left(\frac{H}{B_t}\right)\right]}{2 \cdot K_{\mu'}} \text{ Load coefficient} \tag{8-2}$$

C_t = 0.8509 Load coefficient

$$W_t = C_t \cdot w \cdot B_t^{\,2} - 2 \cdot c \cdot C_t \cdot B_t \text{ N/m (lbf/ft) – Earth load on pipe} \tag{8-1}$$

W_t = 13,314 N/m (953 lbf/ft)

Rectangular Conduit (Trench) - Cast-In-Place

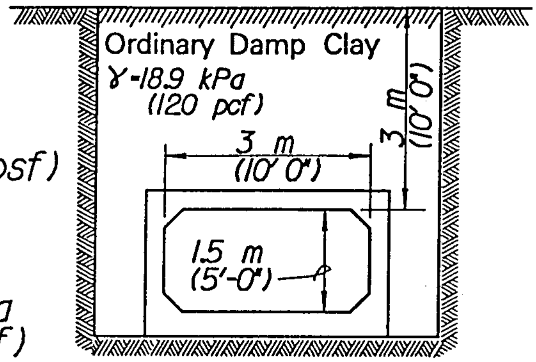
Vertical Pressure

$$We = 18.9\ (3)$$
$$= 57.6\ \text{kPa}\ (1{,}200\ \text{psf})$$

$$Pe_T = \frac{57.6}{3} = 19.2\ \text{kPa}\ (400\ \text{psf})$$

$$Pe_b = \frac{4.5\ \text{m}\ (19.2)}{3.0\ \text{m}} = 28.8\ \text{kPa}\ (600\ \text{psf})$$

Ws = Weight of Structure
kN-m (plf)

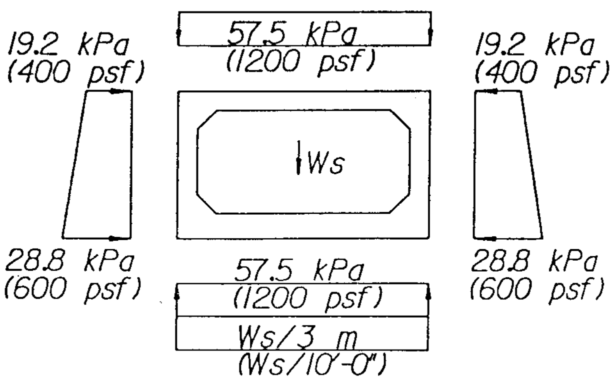


BOX

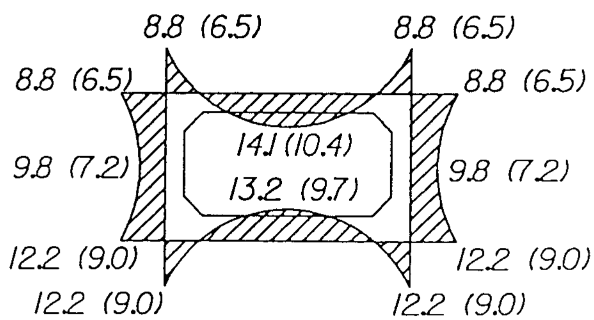
Next calculate FEM's and distribute to design section.
Use load factors from EM 1110-2-2104.

Other Computer programs that can be used to analyze this shaped culvert include CANDE (Culvert Analysis Design), CORTCUL (Design or Investigation of Orthogonal Culverts)

Standard reinforcement for rectangular sections is included in ASTM C789 and C850.



LOADING DIAGRAM



MOMENT DIAGRAM kN–m (K–ft)

Oblong Conduit (Trench) - Cast-In-Place

Vertical Pressure

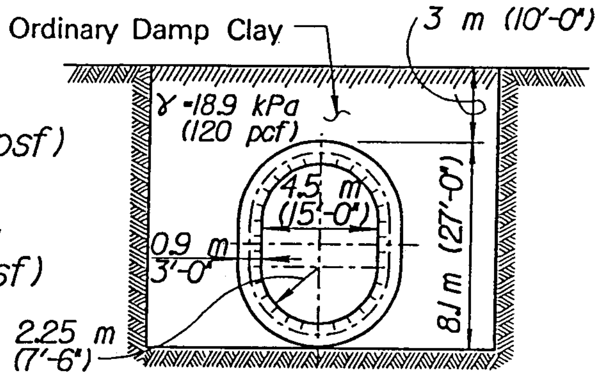
$$We = 18.9\ (3) = 57.6\ \text{kPa}\ (1{,}200\ \text{psf})$$

$$Pe_T = \frac{57.6}{3} = 19.2\ \text{kPa}\ (400\ \text{psf})$$

$$Pe_b = \frac{11.1\ \text{m}\ (19.2)}{3.0\ \text{m}} = 71.0\ \text{kPa}\ (1500\ \text{psf})$$

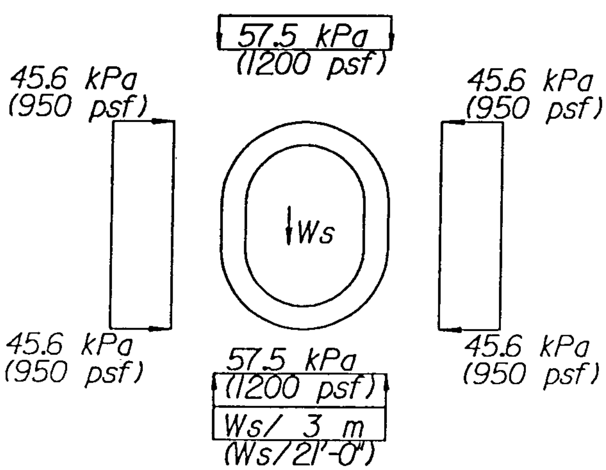
$$W_{avg} = \frac{(Pe_T + Pe_b)}{2} = 45.6\ \text{kPa}\ (950\ \text{psf})$$

Ws = Weight of Structure kN-m (plf)

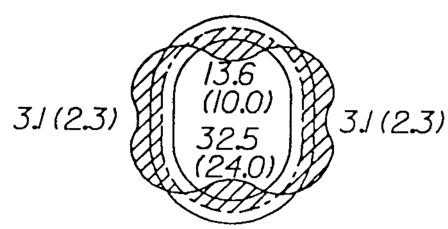


OBLONG PIPE

Moments and shears for this section were calculated using the computer program STAAD III. Other finite element computer programs work as well.



LOADING DIAGRAM



MOMENT DIAGRAM kN–m (K–ft)